NASA-CR-193576

p 30

FINAL

PROGRESS REPORT
for
Grant No. NAG-1-1125

covering the period

3/1/92 to 6/1/93

END-EFFECTOR - JOINT CONJUGATES FOR ROBOTIC ASSEMBLY OF LARGE TRUSS STRUCTURES IN SPACE: EXTENDED CONCEPTS

submitted to
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2. TABLE OF CONTENTS

following items 1. to 6. in the format of
NASA Information Guide to
University Programs 1988, page 22

3. TRANSMITTAL LETTER

following the format of
NASA Information Guide to
University Programs 1988, p.22

a. Organization of origin: Department of Technology
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b. Type of organization: Educational

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e. Date submitted: 6 / 1 / 93

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g. Preliminary reports to NASA-LaRC Technical Officer:

	Division	Branch	Ext	Mail	Bldg	Room
Marvin D Rhodes	SSD	Structural	3121	190	1148	215

h. Proposal is a continuation of previous funding.

i. Funding requested of NASA: \$96,577 Provided: \$87,999

j. Starting Date: 6/1/91 Revised: 9/1/91
Proposed Duration: thru 6/1/92 Revised: thru 1/1/93
Extended: " 6/1/93

k. Project Title: END-EFFECTOR - JOINT CONJUGATES
FOR ROBOTIC ASSEMBLY OF
LARGE TRUSS STRUCTURES IN SPACE:
EXTENDED CONCEPTS

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4. ABSTRACT

Results from NASA/HBCU Grant No. NAG-1-1125 are summarized:

I. Invention Disclosures: LaRC Patent Counsel George Helfrich is pursuing protection for the "Push-Pull Pair" joint preload.

II. Publication (this period only):

A. Papers Published in Conference Proceedings --

5 presented, 6 published at
4 different conferences.

B. Papers Submitted and Pending --

" High Density Launch Packaging of Tubular Components Used for Robotic Assembly of Large Structures in Space ".

III. Designs Developed for Model Fabrication:

A. Bevel Drive Turnbuckle --
Alternatives detailed in Appendix D.

IV. Exploratory Concepts Drafted: (packaging components all related to the subject submitted in II.B. above)

A. Transverse Spring Retracted Bolt and Zip-Nut Recepticle for strut hold-down and location.
B. Retractable Acquisition-Location Studs for component retrieval and manipulation.
C. Bolt Retraction-Extension Drive Mechanism.

V. Interface of Computer with Robot and End-Effector:

A. Robot - shipped to the vendor for repairs.
B. End-Effector - controller hardened in a container.
C. Single Program control over both EE and Robot.

VI. Capability Enhancement:

A. Design Facilities - computers renovatated & updated
B. Fabrication Tools - Moved to temporary storage.
C. Evaluation Equipment - N. A.

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5. PROJECT ACTIVITIES and OUTCOMES

I. Invention Disclosures:

According to LaRC Patent Counsel Geoge Helfrich, publication expedites pursuit of patent protection by his office. Push-Pull Pair concepts were presented in two publications discussed below and referenced [1 and 2]. Patent application must be initiated within a year of publication. Since the first publication was 8 / 92, action on this initiative should be forth coming by 8 / 93.

Patents were sought for four inventions. A determination has been made against pursuit of patents in two of the cases. That leaves the remaining two pending.

II. Publishing Efforts (for this period only) :

A. Papers Published in Conference Proceedings --

Six have been published. Five of these were presented at four different conferences. This was a time consuming process that focused our major effort for this final period. Subjects presented in these publications have been elaborated at length in previous reports where copies of some form of the manuscripts were appended. All are cited in this report under " 7. REFERENCES ". Since they are now in the public domain, only a brief discussion of the motivation for each follows:

[1] " Single versus Double Action Mechanisms ..." introduces the "push-pull pair" concept. Independance of the concept from a particular type of preload mechanism is emphasized and demonstrated with a pair derived from the Turnbuckle double-action mechanism previously published [7].

[2] " Push-Pull Pair of Single Action Mechanisms ..." introduces a very simple and compact "Travel Gear Pair" that is NOT derivable from a double-action mechanism. This is an attempt to more fully exploit the potential of the pair concept.

[3] " Rotation Rectifiers Assist End-Effectors with Robot Mobility ..." discusses various alternatives for robot self-mobility and introduces the "half-wave" rectifier as a competing proposal.

[4] " Full-Wave Bi-directional Rotation Rectifier ..." is primarily concerned with describing the mechanisms themselves rather than a discussion of their efficacy in the robot mobility application.

[5] " Simulated Mechanical Interface for End-Effector, Strut, Node Interactions ..." presents our effort to develop a test facility for evaluation of end-effector sensitivity to misalignment of parts being assembled.

[6] " Development of an Experimental Method to Determine Axial Rigidity of a Strut-Node Joint " is a replication of referenced work at LaRC. The difference is that we modified very inexpensive equipment to repeat the task. The interest here is that educational institutions with modest laboratory budgets can incorporate such an affordable demonstration in their curriculum.

B. Paper Submitted --

To the IASTED International Conference on ROBOTICS AND MANUFACTURING, Christ Church, Oxford England, 9/23/93:

" High Density Launch Packaging of Tubular Components Used for Robotic Assembly of Large Structures in Space".

Positive hold-down and positive hand-off aspects of tubular component storage are addressed with this modular hexagonal close-pack bundle alternative to part trays.

A copy of the manuscript is included in Appendix D. End-effector sub-assemblies needed to extract parts from a close-pack bundle and secure them for manipulation by a robot are discussed below under "IV. Exploratory Concepts Drafted".

C. Abstracts Submitted -- No Activity for this period

D. Papers Reviewed -- No Activity

III. Designs Developed for Model Fabrication:

A. Bevel Drive Turnbuckle --

Note: Part No. designations refer to drawings in Appendix A submitted with the 1st report, 4/30/91 .

Note: Discussion in this section includes abbreviated material from the previous report. It is repeated here to reference detailed drawings now included in accompanying Appendix D .

1) C-TUBE cylindrical alternative to the hexagonal cross-section strut-end housing called the TUBE, part No. 0 --

For prototype fabrication and tensile tests the cylindrical tube stock is readily available, easier to machine, and attaches conveniently to test fixtures.

The cylindrical C-TUBE has an additional pair of transverse holes aft of the mechanism (Appendix D page D-14). The end-effector inserts index pins into these to orient the strut. They may also serve as a grip for tensile testing.

2) C-PLUG is a modified transition PLUG, part No. 13, and companion to the C-TUBE providing additional strength --

A more generous cross-section extends the above mentioned index pin holes increasing their bearing area (page D-15).

3) T-KNOB alternative to T-BAR, SNOB, or TNOB, part No.11--

Tension knob, TNOB, was designed to be installed on the end of the tension rod, TROD, part No.10, so that "pocket scars" could be accomodated. Small Knob, SNOB, was a down-sized modification necessitated by the sizes of slot cutters that are available for machining the node slot or scar pocket.

T-KNOB (page D-16) is an oblong version of SNOB which when installed at the end of TROD forms a T-bar to be used with the slotted node concept described in section II.B.3 of the previous report.

4) Torque Jig for manual application of test preloads --

Bevel gear preload drive conjugates consist of a CROWN GEAR, part No. 2, mounted on the TURNBUCKLE, part No. 1, in the strut-end, and a PINION gear which will be part of the end-effector. To perform tensile tests the end-effector's application of preload torque will be simulated with a Torque Jig. The Jig is shown on page D-13 in assembly with parts described in paragraphs 1) and 2) above.

Torque Jig consists of a split block with a bore of the same diameter as the strut-end housing. It has location pins to orient the C-TUBE. Two pinion bearing carriers, called SPOOLS, are mounted to either side of the split block. These position the pinions in correct alignment with the CROWN GEAR for torque application.

Torque Jig assembly drawing was included in Appendix C and has been repeated in Appendix D on page D-13. Split block halves are identical and bolt together at the corners with socket head screws. One block half is detailed on page D-17.

IV. Exploratory Concepts Drafted:
(all related to compact packaging components, the subject of a paper submitted, II.B above)

A. Transverse Spring Retracted Bolt and Zip-Nut --

Diametrally mounted bolts in one cylindrical component are used to attach it to the next, forming a stack. Multiple stacks make a bundle. Zip-Nut recepticles for the bolts are flush mounted on cylindrical components. The scheme does not depend on Zip-Nuts but is facilitated by them.

B. Retractable Aquisition-Location Studs --

The same recepticles are used by a robot end-effector mounted pickup to extract parts from the storage bundle and manipulate them. Studs need only a bi-directional rotation action to secure a part to the pickup location plate or release it. Under some circumstances it is useful for the studs to retract below the surface of the pickup location plate. A helix retractor and drag clutch mechanism can accomplish this using the same torque motor that rotates and tightens the stud. This mechanism also provides the negative axial retraction force needed to disengage a Zip-Nut.

C. Bolt Retraction-Extension Drive Mechanism --

Retraction-Extension is a required function for driving the attachment bolts (described in IV.A. above) rather than an option as is the case for the Acquisition-Location Studs. A helix mechanism similar to that used in IV.B. can be applied to this function. There are advantages to separating the torque and extension actions so two motors are provided.

V. Interface of Computer with Robot and End-Effector:

A. Robot --

Shipped to the vendor in the spring of '92 for repair and renovation, it was returned during the summer break. Work with it resumed in the fall.

B. End-Effector --

A more robust controller has been assembled into a protective box with surface mounted switchs and cable connections. This makes the unit much more compact, portable and storable. Instructions for set-up and operation are also simplified. These features have been particularly apropos in our current environment: pack-move-renovate-repack-remove. This process is not yet complete at our site.

C. Unified Control --

ATLAS Robots, as supplied from the vendor, could be controlled by an IBM/AT compatible computer using a form of "Basic" programming language which was imbedded in a compiled "C" program. It allowed us to control the Robot only and nothing else. Our end-effector controller was developed using the Turbo-Pascal language.

The key to unified control was an uncompiled version of the ATLAS "C" program. We are indebted to the ATLAS vendors for their cooperation in obtaining a copy from England. With this in hand, the end-effector control program was translated from Turbo-Pascal into "C" and inserted into the ATLAS program. Unfortunately, the versions of "C" compilers available to us would not compile the earlier language in which the bulk of the program had been written. The program had to be rewritten. This deed has been done and the result satisfies our requirement for "unified control".

VI. Capability Enhancement:

A. Design Facilities --

Display resolution has been updated on 2 of our computers. This can be done inexpensively compared to just 2 years ago. One monitor, one controller card, some soft ware, and a considerable amount of time expended, allowed us to update our best unit and add 16 color, 800 x 600 resolution to an older one. Salvaged parts can be used to upgrade from monochrome to color on another.

B. Fabrication Tools --

Progress has been reversed in this area. A "temporary" move has placed all of the machines we had been using for model fabrication into storage. Our computer aided machine tools that have been installed in their new location are not large enough to produce the all of the parts needed to complete an assembly.

C. Evaluation Equipment -- No Activity

6. PERSONNEL

* denotes changes during the period 3/92 to 6/93

I. List of Participants

		area code	phone number	period of partici-pation
Principal Investigator:				
	William V Brewer Associate Professor	601	968 2471	6/90- 6/93
Associate Investigators:				
	Eleftherios P Rasis Professor	"	968 2472	9/90- 5/91
	H R Shih Instructor	"	968 2466	9/90- 5/93
Graduate Students:				
	Manoj K Lakhmani Computer Science	"	968 2466	9/91- 12/92
	Vinod K Kambham Computer Science	"	" "	9/91- 12/91
	Bing Wang Computer Science	"	" "	9/91- 12/92
	* Xiang Zheng Computer Science	"	" "	1/93- 5/93
Undergraduate Students:				
	David I Caddle Drafting & Design Technology	"	" "	9/91- 3/92
	Jacqueline L Morris Pre-Engineering	"	" "	9/91- 12/91

II. Responsibilities of Participants

W V Brewer:

Design mechanical components
Liaison with NASA - LaRC and vendors
Produce proposals and reports
Coordinate task groups

E P Rasis:

Design manufacturing procedures
Supervise hardware fabrication
Acquire necessary machines and tools
Purchase required materials

H R Shih:

Test and evaluate mechanical components
Modify testing machine
Acquire instrumentation
Coordinate work with the Atlas robot

M K Lakhmani:

Design electronic circuits
Integrate electronic components
Harden and package end-effector interface

X Zheng:

Translate end-effector control program from Turbo-Pascal to C-language and insert into robot control program.
Rewrite the unified program to make it compilable.

B Wang:

Test fixture development
Robot operations
Process test data

D I Caddle:

Draft mechanical components
Detail parts
Fabricate mechanical parts

J L Morris:

Enhance CAD software
Setup CAD systems
Draft mechanical components

7. REFERENCES

[1] Brewer, " single versus double action mechanisms for preloading strut to node joints in the robotic assembly of large truss structures in space ", CONTROL AND ROBOTICS, Proceedings of the IASTED International Conference, Vancouver BC, Canada, 8/92

[2] Brewer, " push-pull pair of single action mechanisms to preload strut & node joints in the robotic assembly of structures in space ", ROBOTICS, SPACIAL MECHANISMS, & MECHANICAL SYSTEMS, DE-Vol.45, ASME, New York NY, 9/92

[3] Brewer, " rotation rectifiers assist end-effectors with robot mobility in the automated assembly of large truss structures in space ", CONTROL AND ROBOTICS, Proceedings of the IASTED International Conference, Vancouver BC, Canada, 8/92

[4] Brewer, " full-wave bi-directional rotation-rectifier to assist robotic end-effectors in the automated assembly of truss structures in space ", same as [2] above, 22nd Biennial Mechanisms Conf., Scottsdale AZ, 9/92

[5] Brewer, A S Samavi, " simulated mechanical interface for end-effector, strut, node interactions in the robotic assembly of large truss structures ing space ", MODELLING, SIMULATION & IDENTIFICATION, proceedings of the Pacific-Rim Int'l Conf.,IASTED, Vancouver BC, 8/92

[6] Shih, H R, Brewer, W V, " development of an experimental method to determine the axial rigidity of a strut-node joint ", National Educators' Workshop, NEW:Update '92, Oak Ridge TN, 11/92

[7] Brewer, " simplified double action mechanism to preload joints for robotic assembly of structures in space ", MANUFACTURING & ROBOTICS, 14th IASTED Int'l Symposium, Lugano, Switzerland, ACTA Press, Zurich, 6/91

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8. APPENDIX D

Appendices A thru C are not repeated here but were appended to the three previous reports.

Page numbers are at the top of each page. Appendices follow the outline of the ABSTRACT on page 4.

HIGH DENSITY LAUNCH PACKAGING OF TUBULAR COMPONENTS USED FOR ROBOTIC ASSEMBLY OF LARGE STRUCTURES IN SPACE

W V Brewer

NASA Langley Research Center and NASA Marshall Space Flight Center grants to the Technology Department of Jackson State University
Jackson MS 39217, USA

ABSTRACT

"Hex-Close-Pack" maximizes the density of tubular components for transportation to a space assembly site. Packaging techniques are modified for compatibility with robotic assembly equipment while still conforming to the usual requirements for space applications: positive hold-down, positive hand-off, launch dynamic loads. Close-pack technology is compared with current robotic storage and manipulation methods that are being developed for space applications.

INTRODUCTION

As space structures grow in size, deployable Shuttle packages will not be adequate. Alternatives include the launch and docking together of large packages or the assembly of structures from smaller modular components transported by a "shuttle" vehicle. Most proposals for modular assemblies are in the form of a space truss composed of structurally efficient cylindrical strut tubes. Many struts would be needed and they are usually of the same diameter to take advantage of fabrication and storage economies that accompany modularity. Additionally, fluid transfer requirements are likely to be implemented with cylindrical piping. Active cooling of structural members has been suggested as advantageous for strength retention in high temperature applications such as the Aerobrake. Cylindrical members could combine the structural and fluid transport functions for such applications. Large quantities of cylindrical components would best be bundled in "hex-close-pack" for shipment to the construction site.

Modular components can be assembled by men in space suits. As the size of structures grow, manual assembly becomes increasingly unattractive. Robotic assembly is worth exploring for large structures.

PREVIOUS WORK

In 1987 work was initiated at NASA Langley Research Center (LaRC) on the Automated Structural Assembly Laboratory (ASAL). Figure 1 shows a commercial robot mounted on a gantry-like carriage, traversing a beam, which itself moves longitudinally with respect to the turn-table on which a test structure is assembled. This structure is composed of identical .025m diam. x 2m struts assembled into an 8m diam. x 1.5m deep tetrahedral platform truss. The 102 component struts are stored behind the robot on pallets. Each pallet contains 13 struts in a single layer, spaced so that the end-effector shown at the top of the figure can insert gripper jaws to retrieve them. A stack of 8 such pallets is needed to complete this relatively small truss. A thorough description of all components associated with the ASAL facility has been published as a NASA Technical Memorandum [1].

Marshall Space Flight Center (MSFC) is developing welding as a method of joining cylindrical components for in-space construction. The Aerobrake has been a focus for this effort. Preliminary investigations indicate sizable improvements in structural efficiency if 3 different strut diameters are incorporated in the brake support truss [2]. A robotic end-effector is being developed to meet the variable diameter requirement [3].

Active cooling of the structural members was proposed for strength retention in the high temperature environment expected for the Aerobrake support structure. Telescoping nested strut tubes, made of fiber composite materials with weldable aluminum end pieces, offer some advantages for the assembly of accurate welded truss structures [4]. Additional packaging and storage efficiencies for these struts are a by-product of this approach.

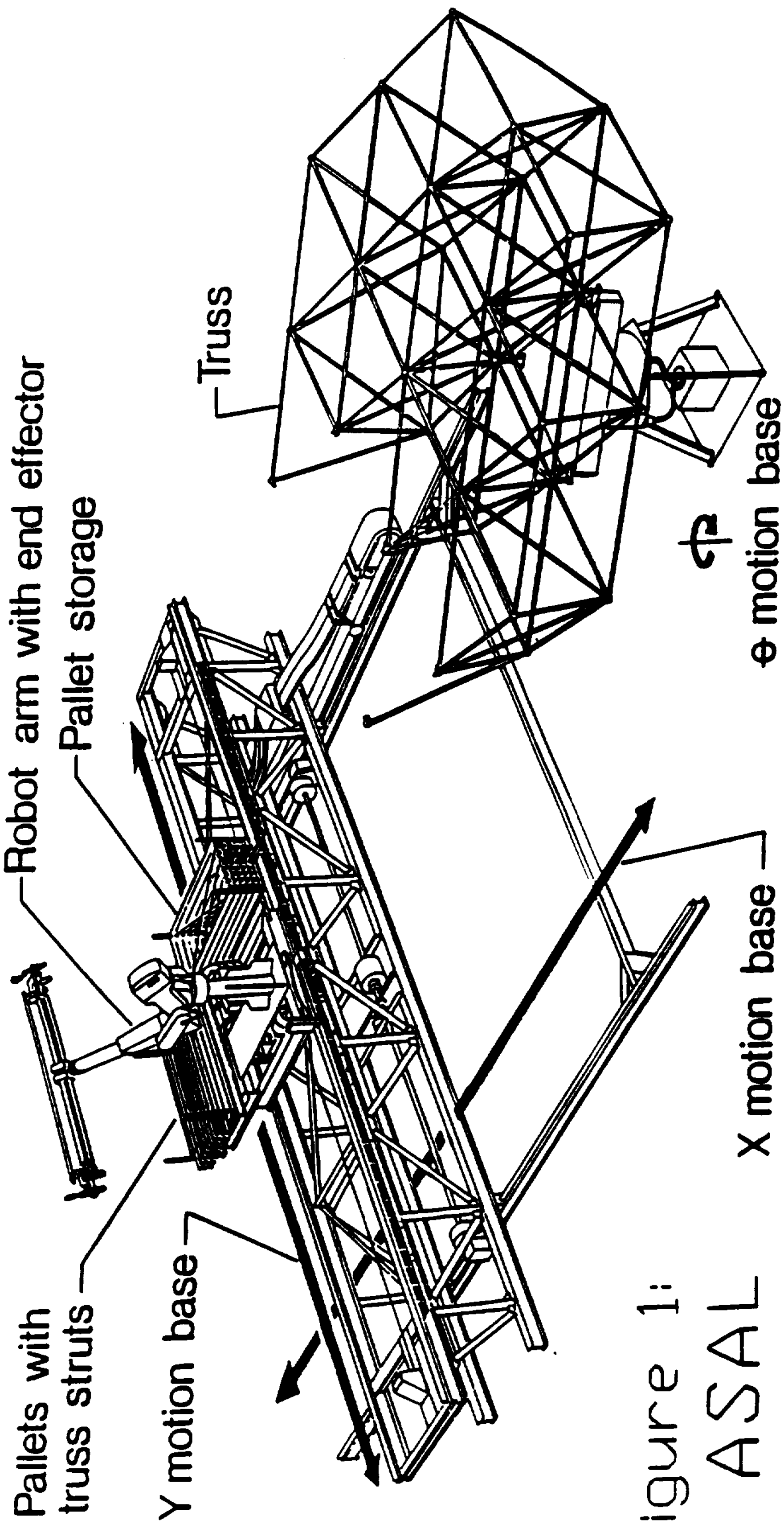


Figure 1: ASAL

PROBLEM

Two mandible jaws have been the rule for robot end-effectors that manipulate components to be assembled in orbit. Vacuum pickups don't work without an atmosphere and magnetic component materials are unlikely to gain acceptance because they tend to be heavy. Space must be provided on opposite sides of a stored object to be grasped so that the mandibles can be inserted. Close-pack storage of components is not possible with this type of end-effector without some form of part dispenser. Active dispensers add complexity to the component storage and delivery system. The twin horns of this dilemma are complexity vs. package density: how to get more of the latter with less of the former.

ALTERNATIVES

Passive storage currently employed in the ASAL project places strut components on the pallets described above. Careful design of pickup mandibles minimizes center spacing between strut tubes on a pallet (1.75 x strut diameter). Pallets of tubes are manipulated with the same pickup system. Pallet spacing in the stack is not as compact (2.5 diameters). Struts are retained on the pallet by spring-loaded detentes mounted in posts that also act a spacers. Pallets are held in the stack by the same method. Such hold-down techniques are not intended to support launch and in-orbit activity.

Active part dispensers are being used extensively for earth-bound manufacturing. They often depend on gravity to function properly. Dispensers have been considered for space applications, but very little work has been published on this subject related to robot operations. Dispensers facilitate high density packaging but introduce additional control system complexity and mechanical reliability issues.

High density, close-pack, passive, storage is proposed here. Positive hold-down and hand-off, compatible with robotic operations, is achieved by introducing staggered stacks. Packaging efficiency is only slightly degraded.

PACKAGE CONFIGURATION

The ASAL passive strut storage system is used as a basis to compare package density. It uses a conventional two-mandible jaw for component retrieval. Specifications in Figure 2 are expressed as multiples of the strut diameter. End views of 3 different configurations of close-pack bundles are shown. Each contains approximately 100 tubes, the number used in the ASAL test structure.

DENSITY COMPARISON

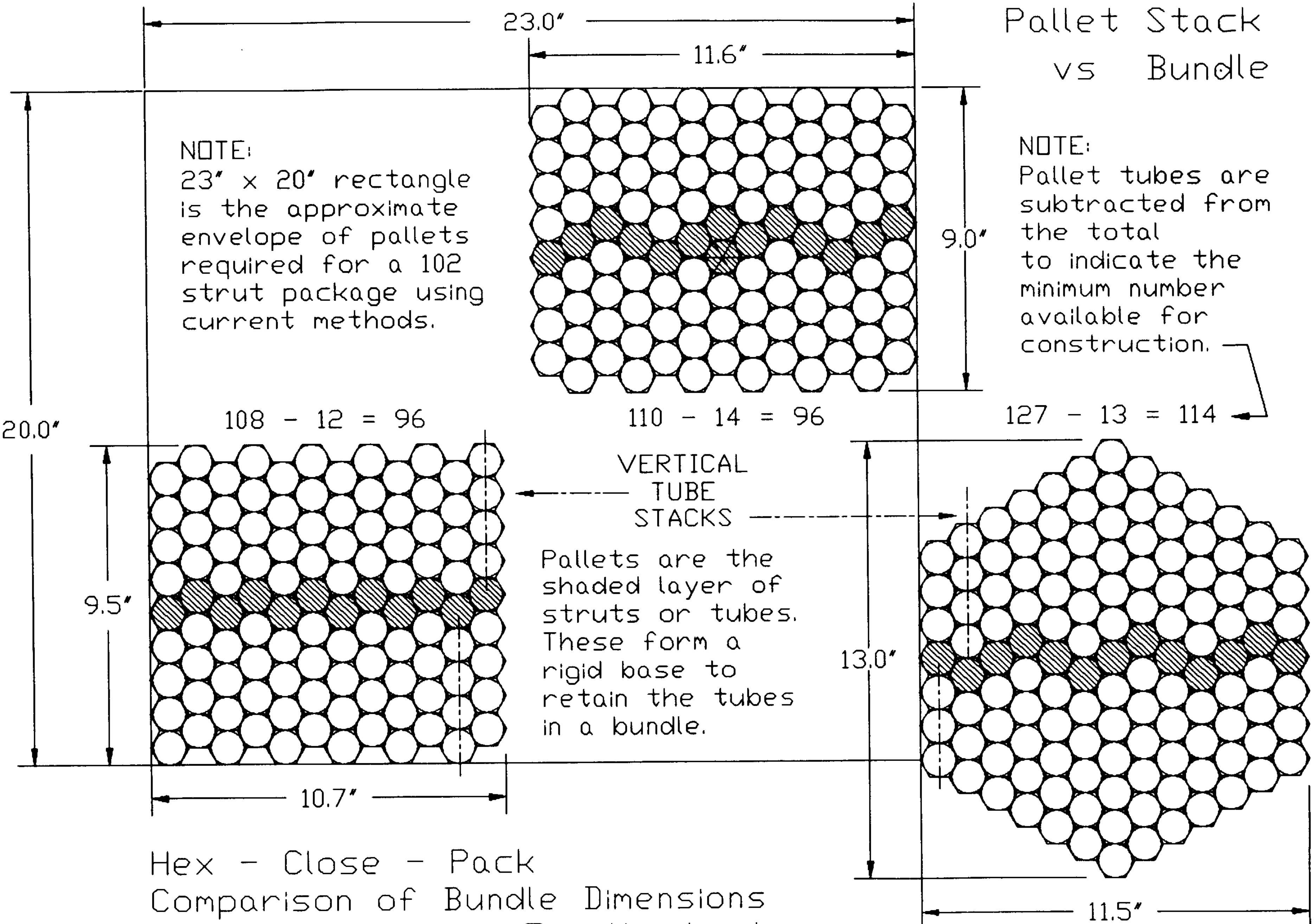
The rectangle dimensioned "23x20" represents an end view of the envelope of an 8 pallet stack containing the 102 struts used by ASAL to complete a 2 ring test truss shown in Figure 1. Aerobrake would require 5 rings [2]. The number of struts used is roughly proportional to the square of the number of rings. Aerobrake would need approximately 625 struts. For this application, 6 stacks of 8 pallets each would not suffice. The equivalent close-pack bundle would fit into less space than 2 pallet stacks. As can be seen in Figure 2, package density of the close-pack bundles exceeds that of the trays by a factor of 4+.

PALLET STACK vs BUNDLE COMPARISON

In the ASAL assembly scenario, empty pallets are removed from the supply stack and placed in a separate pile (empty pallets are stored and shuttled back to earth since jettisoning in orbit is not an option). Pallet removal must be done after every 13 struts assembled, 8 times per 104 struts. The process would be repeated 48 times to assemble a 5 ring Aerobrake. Full stacks would have to be replenished and empty stacks removed approximately 6 times, depending on the capacity of the supply racks mounted on the robot carriage.

Close-pack bundles have a "pallet layer" in the middle. The pallet layer (shown shaded in Figure 2) is composed of special strut tubes connected together laterally at points along their planes of mutual contact. Struts each attach to an identical one immediately below, forming vertical stacks one diameter in width. The strut at the bottom of a stack is attached to the pallet layer. Vertical stacks attach to both the top and bottom

Figure 2:
Pallet Stack
vs Bundle



Hex - Close - Pack
Comparison of Bundle Dimensions
for Approximately One Hundred
UNIT Diameter Tubes

of the pallet layer. They interlock to form a reasonably robust, compact bundle. A novel strut pickup on the robot end-effector (discussed below) may select any strut in the upper-most layer. When all the upper layers are exhausted the bundle is flipped over making the bottom stacks accessible. Far less package manipulation is required with the close-pack system. Bundles of 100 would have to be flipped only after 50 struts are assembled. Aerobrake assembly could be accomplished using a bundle the size of an ASAL 8 pallet stack discussed above. It wouldn't have to be flipped until more than 200 struts are assembled. Less than 2 bundles would be required to complete a 5 ring truss of 625 struts. Empty pallet storage and return may be eliminated entirely. With careful design of the special struts that compose the pallet layer it may be possible to disassemble the pallet one strut at a time and incorporate it into the assembled structure.

PROPOSED PART PICKUP

Positive part hand-off requires the end-effector to grasp a part securely before it is released from the storage bundle. Passive storage implies that the end-effector is responsible for both actions: grasp of the part and extraction from storage.

GRASP

End-effector jaws are replaced by studs that are inserted into threaded receptacles in the side of a part to be manipulated. Approach of the part is possible without providing access space on three sides to allow jaw insertion. Once inserted the studs are turned to bolt a part tightly to the end-effector. Assembly is facilitated by using a flush mounted "Zip Nut" for the stud receptacle. Zip Nuts allow the stud to be inserted without turning. Once inserted it can be tightened as with any thread by turning. It cannot be removed without turning in the opposite direction. Problems with thread alignment, cross threading and thread damage require far less attention. These devices have been proposed by MSFC as a feature in the design of robot compatible joints for large components assembled on-orbit [5] and as part of the alignment process for welded tubular struts [3]. A disadvantage of the Zip Nut is the need for a negative force as well as negative rotation to disengage.

EXTRACTION

After the part is secured to the end-effector it can be removed from the supply bundle. Struts in the bundle are secured in vertical stacks as described above. Each is attached to one below with bolts mounted diametrally in the strut as shown in side view in Figure 3. The stack is staggered in the axial direction relative to the strut so that struts can be made identical and therefore interchangeable. A second Zip Nut site is provided for this purpose. Some package density is sacrificed on this account. Bolts are a little less than a strut diameter in length and lightly spring loaded so they retract completely when not in service.

A bolt driver in the pickup mechanism must be capable of replacing a part back into the bundle and indeed reassembling the whole bundle if necessary to meet all possible contingencies.

PART PICKUP STUD

In its simplest form, a pickup stud need only turn in both directions. It would be possible to secure and locate a part with a single active stud as shown in Figure 4 (lower middle) and passive alignment pins. The pins could be fixed or spring loaded. With a spring, Figure 4 (lower right), they would assist with disengaging the Zip Nut. In the absence of some form of "push-off", careful coordination between stud rotation and end-effector withdrawal motion is necessary. With a double-ended end-effector such as that used in the ASAL facility, a stud at each end would be the most likely configuration. Single-ended end-effector designs may employ multiple studs to accomplish other objectives: greater reliability thru redundant systems, ease of part acquisition, additional grasp strength.

Variable grasp strength is possible by using a battery of studs. Large parts would activate more studs. Fewer would be needed for smaller ones. Aerobrake is an application where strut sizes vary in both length and diameter. Fluid transport would be less restricted in piping where smaller Zip Nuts and hold down bolts occupy less of the cylindrical cross-section. Several smaller ones could be used to maintain the same grip strength.

Figure 3:
Part Stack

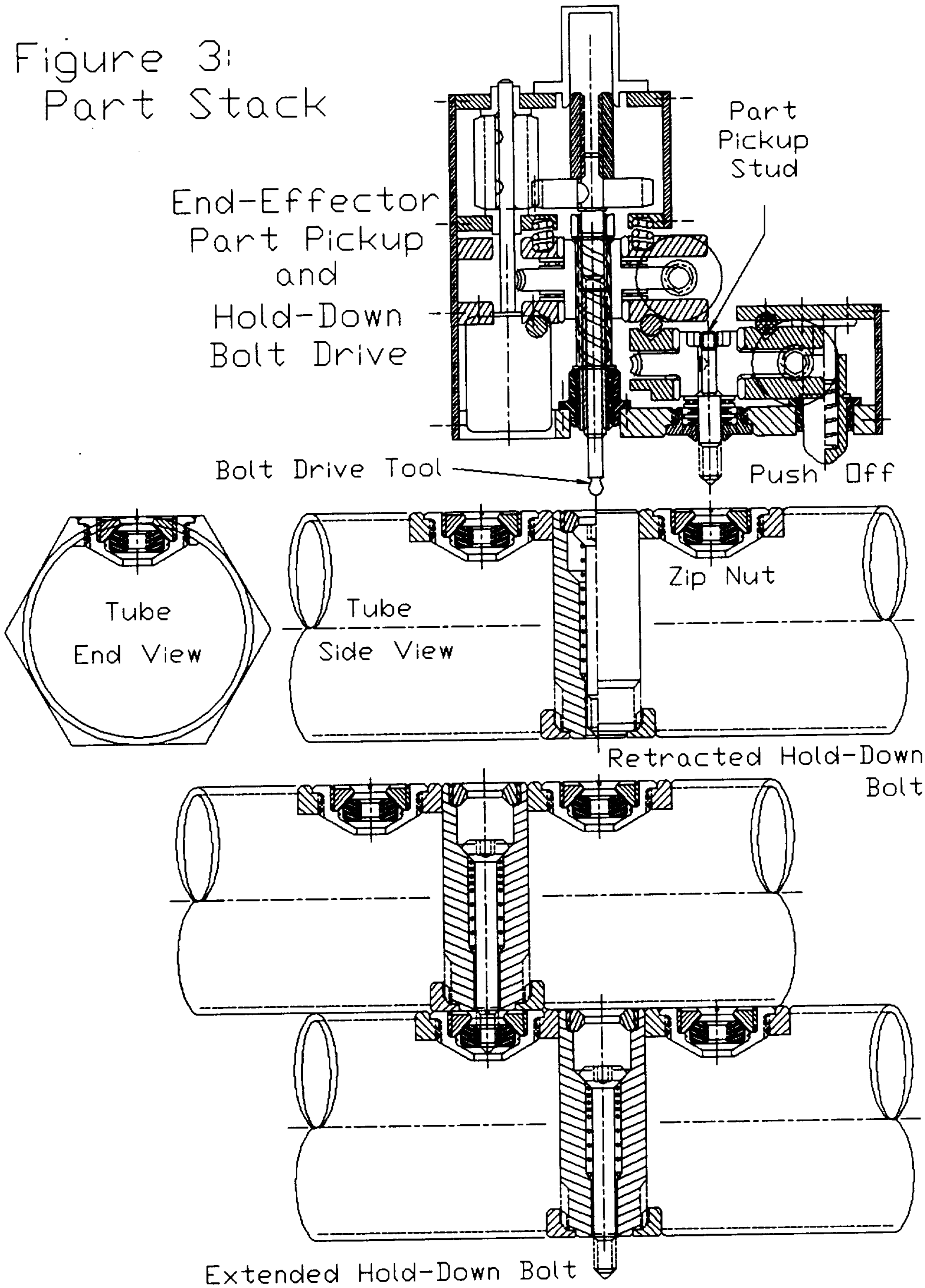
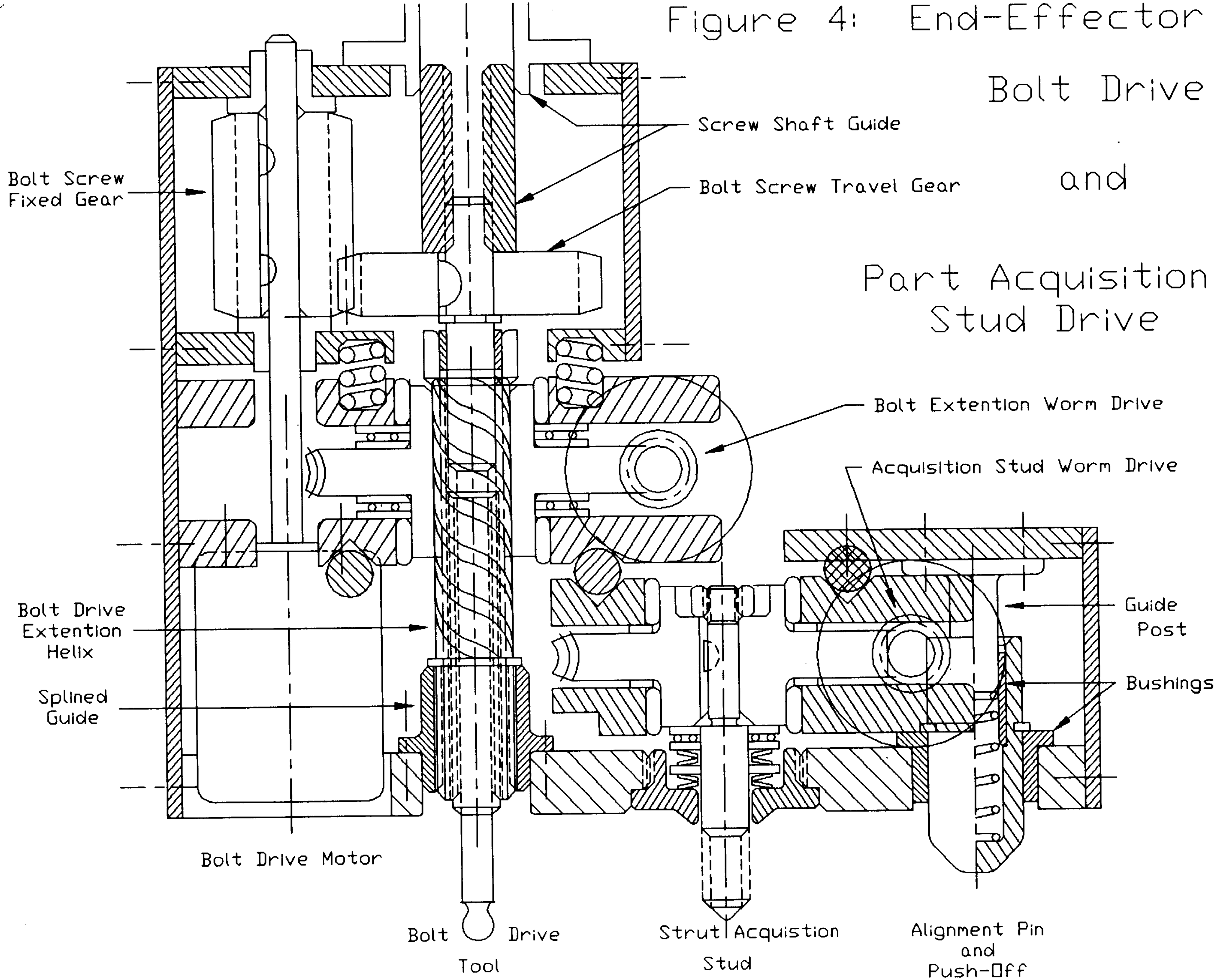


Figure 4: End-Effector Bolt Drive and Part Acquisition Stud Drive



HOLD-DOWN BOLT DRIVER

Two actions are needed: extension / retraction; rotation in both directions. To detach a part from the bundle a driver tool is inserted into the drive socket in the bolt head, then negative torque is applied to loosen the part. A bolt will not come out of its Zip Nut receptacle unless the drive tool is withdrawn simultaneously so the bolt retractor spring can apply the required negative force. These activities would have to be coordinated so the drive tool remains in the bolt drive socket without applying any positive force to it.

Alternatively, Figure 4 shows the drive tool mounted on a screw of the same thread lead as the hold-down bolt. That causes rotation and retraction to occur at the same rate in both. Standardization of thread leads for all parts to be assembled with the same end-effector would be desirable if this option is implemented.

Reassembly of the supply bundle is less complicated. The drive tool is inserted into the bolt head socket, then pushes until the bolt is extended from the side of the strut and into a receptacle in the part beneath it in the part stack. Positive rotation tightens the bolt securing its part to the bundle.

CONCLUSIONS

1. Close-Pack Bundles are the best package for large quantities of cylindrically shaped components.
2. Passive storage reduces system complexity.
3. Robot compatible Passive Close-Pack Bundles are feasible.
4. Package density can be increased by a factor of four.
5. Pallet manipulation operations are simplified.
6. Empty pallet storage and return may be eliminated.
7. Stud/Zip-Nut part pickup and hold-down systems facilitate Passive storage in Close-Pack Bundles.
8. Access is provided on only one side of a part in storage instead of three with conventional methods.
9. Proposed methods and benefits are easily extended to robot maneuver of other objects.

ACKNOWLEDGMENTS

Assistance of Marvin D. Rhodes is much appreciated.

Support from the HBCU program at NASA/LaRC was instrumental.

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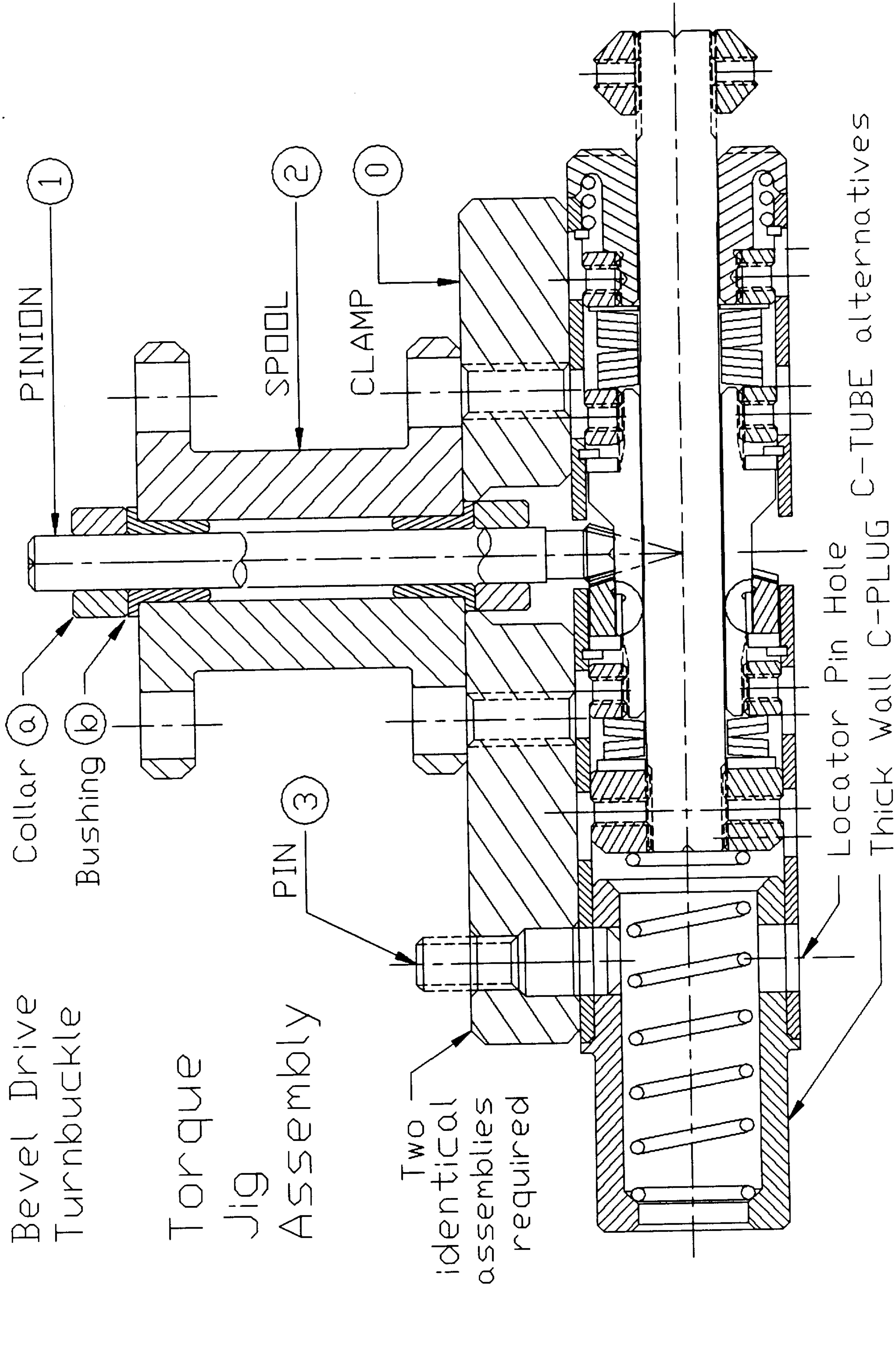
[1] Rhodes, M. D., Will, R. W., Wise, M. A., "A Telerobotic System for Automated Assembly of Large Space Structures", NASA Technical Memorandum 101518, LaRC, Hampton VA 23665, 3/89

[2] Thomson, M., ORBITAL CONSTRUCTION DESIGN DATA HANDBOOK, AAC-TN-1160, for NASA/LaRC, NAS1-18567, Task 7, Astro Aerospace, Carpinteria CA, 1990

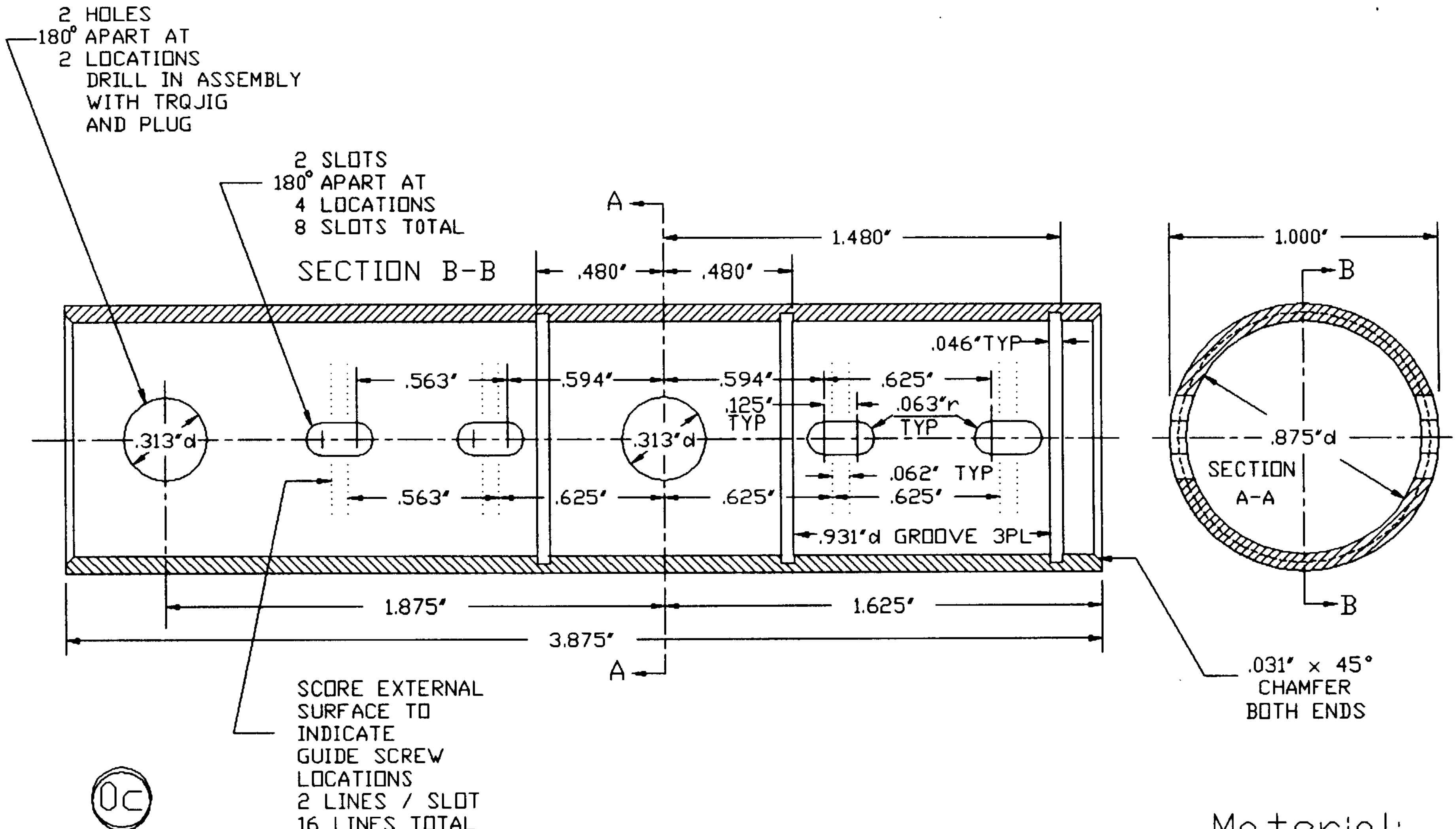
[3] Jones, C. S., Thomas, F. P., Brewer, W. V., "Robotic Assembly of Welded Truss Structures in Space", FLEXIBLE ASSEMBLY SYSTEMS, DE-Vol.48, ASME, New York NY, 9/92

[4] Rule, W. K., "Design of a Welded Joint for Robotic, On-Orbit Assembly of Space Trusses", RESEARCH REPORTS, 1992 NASA/ASEE Summer Faculty Fellowship Program, MSFC, UA, UAH, NASA CR-184505, Huntsville AL 35812, 12/92

[5] Williamsen, J., Thomas, F., Finckenor, J., Spiegal, B., "Definition of Large Components Assembled On-Orbit and Robot Compatible Joints", NASA TM-100395, MSFC, Huntsville AL, 1990


Bevel Drive
Turnbuckle
Torque
Jig
Assembly
PINION
1
SPOOL
2
CLAMP
0
Collar a
Bushing b
PIN
3
Two
identical
assemblies
required
C-TUBE alternatives
Locator Pin Hole
Thick Wall C-PLUG

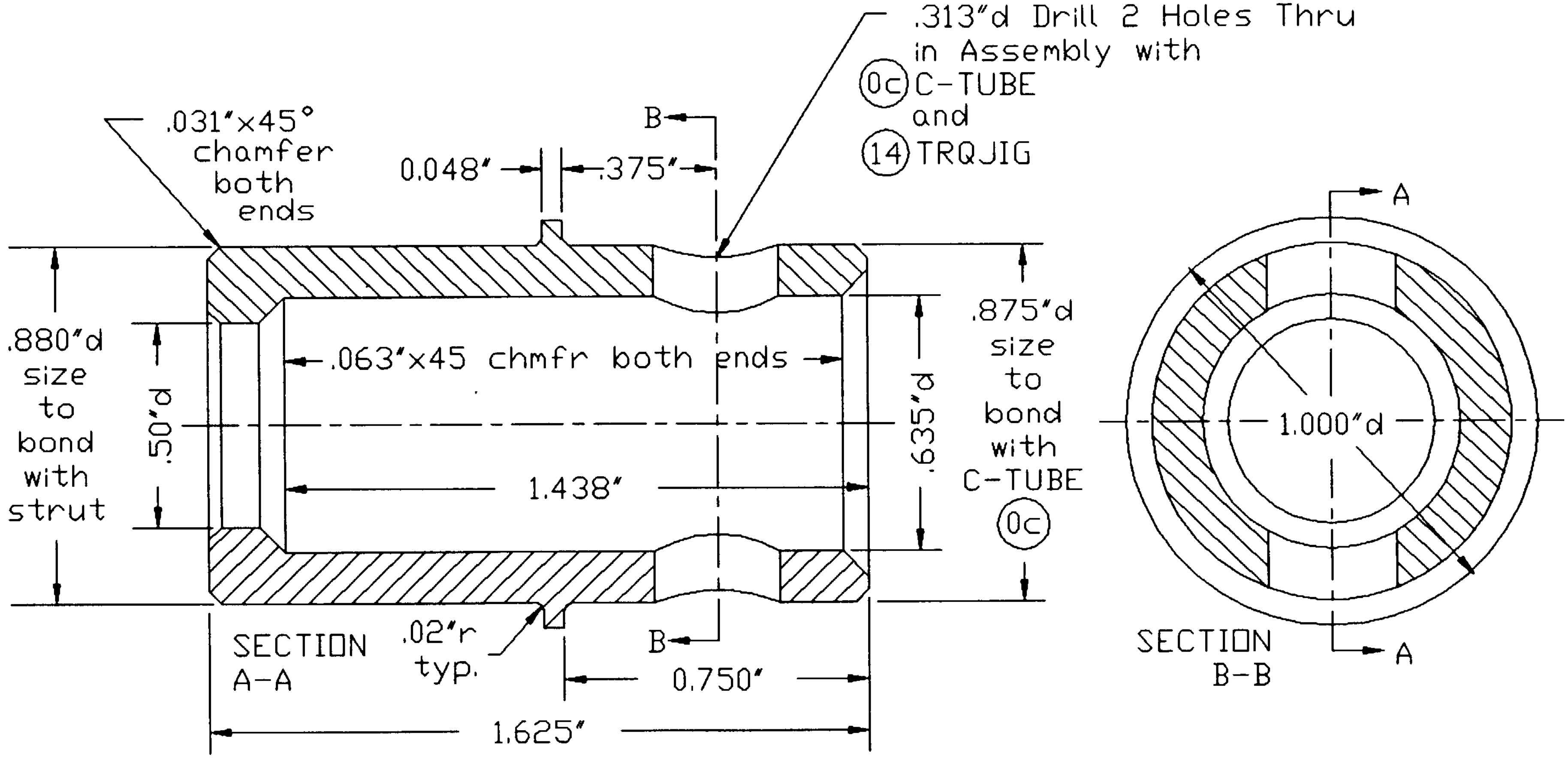
Bevel Drive Turnbuckle



C-TUBE
Cylindrical Tube
(Alternative)

Material:
Aluminum
Tube
Stock

Bevel Drive Turnbuckle

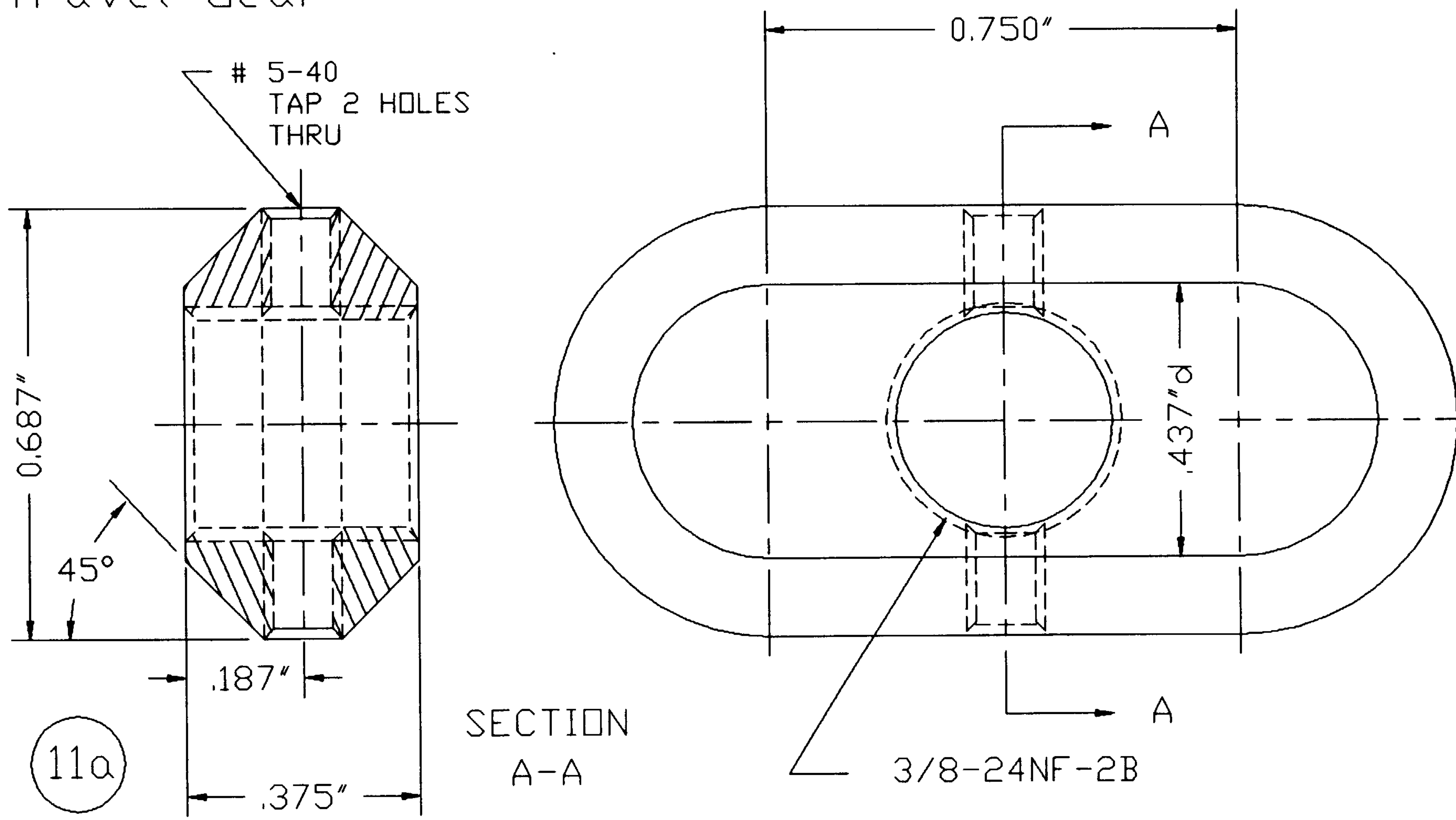


13c

C-Plug

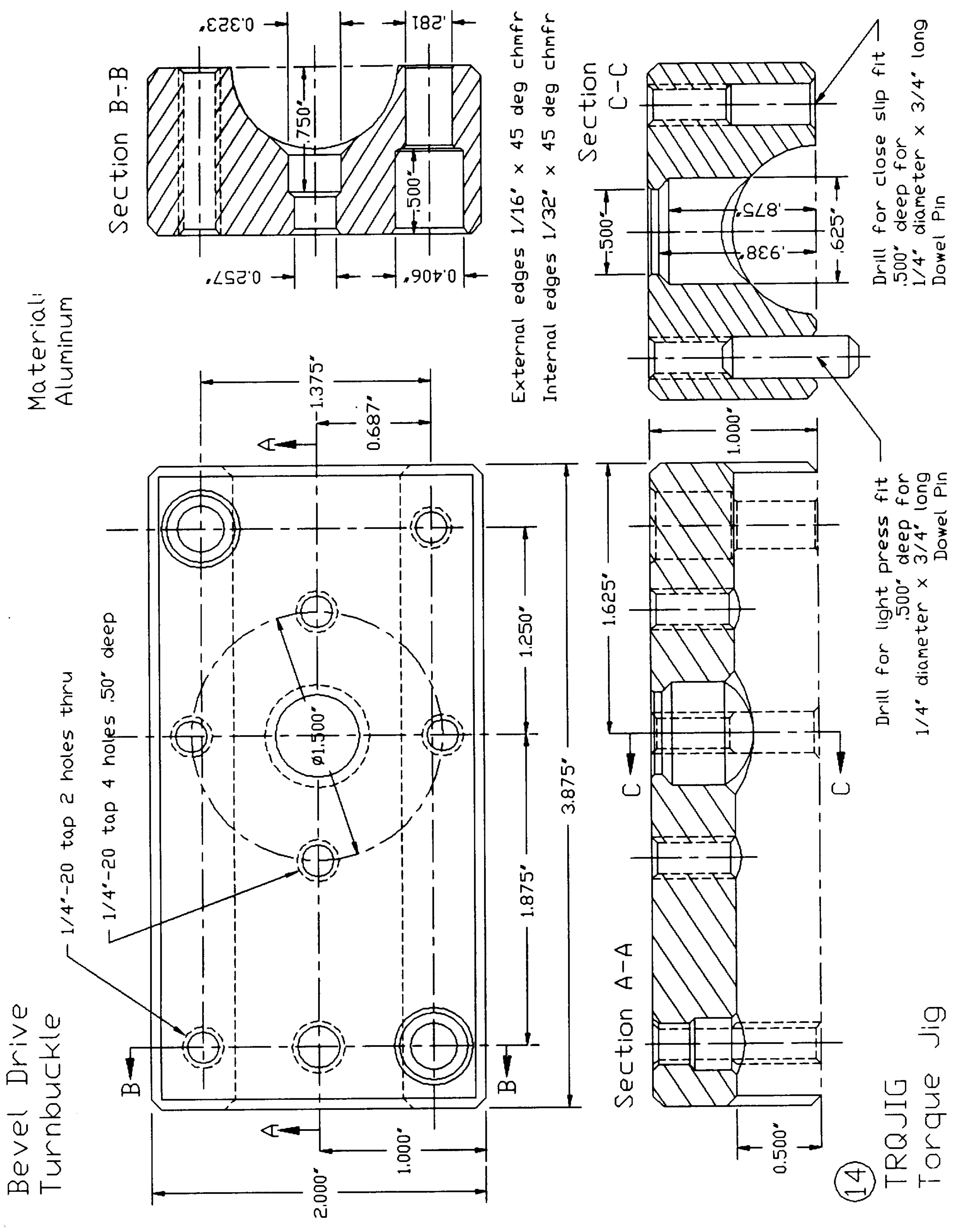
Material:
Aluminum

Bevel Drive Turnbuckle
or
Push-Pull Pair 3p/tg
Travel Gear



STNOB
Small T-Knob

Material: Aluminum
1 Req'd. for BDT
2 Req'd. for 3P/TG


Bevel Drive
Turnbuckle
Material:
Aluminum
1/4"-20 tap 2 holes thru
1/4"-20 tap 4 holes .50" deep
ø1.500"
1.375"
0.687"
1.250"
1.875"
3.875"
1.000"
2.000"
A
B
Section B-B
0.323"
.281
.750"
.500"
0.257"
0.406"
External edges 1/16" x 45 deg chmfr
Internal edges 1/32" x 45 deg chmfr
Section C-C
.500"
.875"
.938"
.625"
Drill for close slip fit
.500" deep for
1/4" diameter x 3/4" long
Dowel Pin
Section A-A
1.000"
1.625"
0.500"
C
Drill for light press fit
.500" deep for
1/4" diameter x 3/4" long
Dowel Pin
14
TRQJIG
Torque Jig